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ELECTRICITY SUPPLY SYSTEM

Technical field:

The present invention relates to an electricity supply system for traction, i.e. a plant for supplying power to railway locomotives, motor coaches, streetcars and like vehicles in which at least one electric machine included in the plant is provided with a magnetic circuit comprising a magnetic core and at least one winding.

Background art:

The magnetic circuit in an electric machine usually comprises a laminated core, e.g. of sheet steel with a welded construction. To provide ventilation and cooling the core is often divided into stacks with radial and/or axial ventilation ducts. For larger machines the laminations are punched out in segments which are attached to the frame of the machine, the laminated core being held together by pressure fingers and pressure rings. The winding of the magnetic circuit is disposed in slots in the core, the slots generally having a cross section in the shape of a rectangle or trapezium.

In multi-phase electric machines the windings are made as either single or double layer windings. With single layer windings there is only one coil side per slot, whereas with double layer windings there are two coil sides per slot. By coil side is meant one or more conductors combined vertically or horizontally and provided with a common coil insulation, i.e. an insulation designed to withstand the rated voltage of the machine to earth.

Double-layer windings are generally made as diamond windings whereas single layer windings in the present context can be made as diamond or flat windings. Only one (possibly two) coil width exists in diamond windings whereas flat windings are made as concentric windings, i.e. with

widely varying coil width. By coil width is meant the distance in arc dimension between two coil sides pertaining to the same coil.

Normally all large machines are made with double-layer winding and coils of the same size. Each coil is placed with one side in one layer and the other side in the other layer. This means that all coils cross each other in the coil end. If there are more than two layers these crossings complicate the winding work and the coil end is less satisfactory.

For historical reasons a number of supply systems with different voltage and frequency have been developed for railway operation. Once a system has become established in an area, changing to another system entails vast expense and disturbance in operation. In principle there are three standard solutions for supply voltages, direct voltage systems, public frequency alternating voltage systems and low frequency alternating voltage systems. This has meant that many traction vehicles (locomotives and motor coaches) and passenger coaches must be built for more than one supply system. Locomotives and coaches for integrated traffic between different countries exist today which can manage different supply systems and/or variations within the same supply system.

Electric energy for track supply can either be taken from the general distribution network or be generated in power stations run by the railway. The arrangements will differ depending on whether the supply is alternating or direct current tension. In the case of direct current electrification rectifier stations are required for conversion from the alternating voltage supplied by the public distribution network. These rectifier stations supply direct voltage at certain points along the railway. In the case of alternating current electrification with industrial frequency (50 or 60 Hz) transformer filters preventing harmonics generated in the locomotive thyristor

drives from being injected into the public power system and installations for balancing of traction loads are necessary at certain points. The transformation from three-phase to two-phase can also be effected with a special transformer connection, e.g. a Scott connection. A drawback with this type of connection is that it requires many windings and a large core mass. Further drawbacks are that the public frequency supply system has low power transmission capability and high inductive losses compared to a low frequency system, and that the traction load generates disturbances into the feeder network. In the case of electrification with low-frequency alternating current ($16\frac{2}{3}$ or 25 Hz), converter stations are required to convert the voltage from the industrial frequency of the public distribution network, or special power stations and special distribution networks for the low-frequency alternating current.

Direct-voltage electrification was chosen originally because a suitable and simply controlled motor, the series-excited direct current motor, was available. Previously three-phase alternating voltage was converted to direct voltage with the aid of rotating converters or mercury arc rectifiers, but nowadays the conversion is usually carried out with 6 or 12-pulse relays.

The direct voltage system has the advantage that the current can be used directly in direct current motors. No heavy transformer is required in the vehicle to step-down the voltage as is the case with alternating voltage. Vehicles supplied with direct voltage are therefore somewhat less expensive and easier to produce. The low direct voltage is an advantage from the safety aspect (for instance in underground railways where power busbars are used which may sometimes be exposed).

The drawback with direct voltage operation is primarily the low voltage which means that the current, and consequently the voltage drop and losses, are considerable.

This must be compensated by large conductor areas and closely spaced rectifier stations (normally less than 10 km between stations). This results in expensive plants. The drawbacks are particularly noticeable at high power such as with high-speed traffic. Rectifier stations with high power must be built close together, and are only used during the short time the train passes the supply station in question. Another drawback is extremely large short circuit currents.

Before it became possible to use industrial frequency (50 or 60 Hz) for traction motors, the first alternating voltage systems were electrified with low-frequency voltage (15 to 16⅔ or 25 Hz). The traction motor used for a long time in such systems was a single-phase series commutator motor, also known as a single-phase traction motor. This functions almost like a direct current motor except that both field and rotor current are reversed every half period since it is supplied with alternating current. To get the commutation to function without damaging over-voltages or electric arcs, low frequency and motors with low speed had to be chosen. An advantage with low frequency alternating voltage, compared to public frequency, is the better power transmission capability.

The main advantage with alternating systems as opposed to direct current systems is that the alternating voltage can be transformed (even though direct voltage can nowadays be transformed with so-called choppers). It is thus possible to maintain a relatively high voltage on the overhead conductor in relation to the voltage with which the motor operates. Due to the high voltage in the overhead conductor the current becomes lower, thus giving better power transmission ability and lower losses in the line network. Supply stations can be located far apart (30-120 km). A drawback is, however, that the traction motors are large and the control technology is complicated.

Another drawback is the need for frequency converters where motor generators would normally be used, i.e.

generally a 50 Hz synchronous motor, which drives a single-phase 16⅔ Hz synchronous generator. For asynchronous connection, the 50 Hz motor/generator is asynchronous with a special rotor supplied with very low frequency a.c. (Scherbius engine). Power can be fed in both directions. The motor has three times as many poles as the generator. The rotating converters are built for a rather low nominal voltage (6 kV) so as to avoid the insulation having to be too strong. Transformers are therefore required both before and after the converters. Several converters are usually operated in parallel in the same plant.

Rotating converters, which may be synchronous or asynchronous, can produce reactive power which is able to compensate the reactive power losses arising in the overhead conductor network and in the vehicle. The rotating converter also provides electric separation between the public distribution network and the overhead conductor system. Reactive power can be supplied to the public distribution network by the rotating converter.

The main drawback of rotating converters is that start-up of the large synchronous/asynchronous machines is time-consuming and phasing in is complicated. It must be possible to satisfy a sudden demand for power. The machines must therefore be run as reserves at no load or with lower power for long periods. Another drawback is the energy losses which are partly caused by the above-mentioned operation at no load.

In new installations the rotating converters have been replaced by static converters. Static converters can produce reactive power which is able to compensate for the reactive power losses arising in the overhead catenary wire. However, the harmonics are higher on both the three-phase and the single-phase side. Furthermore, static converters are unable to generate reactive power to compensate voltage drops caused by inductive load.

As is clear from the above, the various systems used for electrically operated railways are relatively complicated and expensive.

Machines of the above-mentioned type, with conventional stator winding, cannot be connected to a high-voltage network at e.g. 145 kV without the use of a transformer to lower the voltage. The use of a motor in this way, connected to the high-voltage network via a transformer, entails a number of drawbacks as compared with if the motor could be connected directly to the high-voltage network. The following drawbacks may be noted, among others:

- the transformer is expensive, increases transport costs and requires space
- the transformer lowers the efficiency of the system
- the transformer consumes reactive power
- a conventional transformer contains oil, with the associated risks
- involves sensitive operation since the motor, via the transformer, works against a weaker network.

Description of the invention:

The object of the present invention is to provide an electricity supply system and components therefor for electric railway operation and the like, which solves some of the problems inherent in known systems in this area.

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~~The present invention provides an electricity supply system according to any one of claims 1, 2, 6, 9, 11, 17, 18 or 19, each of which claims has an identical characterising portion.~~

The invention is thus based on a special technique for constructing electric machines, motors, generators, transformers, etc. in which the electric windings are produced with dry insulation in a special manner. This permits either elimination of the transformer and/or the

construction of transformers without the drawbacks inherent in conventional ones that have been mentioned above.

The supply system may include machines of various types in a single installation arranged to transmit power from the distribution network to the traction supply line, which generally consists of an overhead catenary wire. It may naturally also include one or more of such special machines combined with conventional machines.

Thus a machine of the type to which the invention relates may be a transformer or a motor generator operating as a converter. These alternatives may of course be combined.

The supply system and the components according to the invention can be adapted to the requirements of various railway systems and, with applicable modifications, are intended for railway systems with an external power supply or with their own power generation system, for railways with different voltage levels and different frequencies and for both alternating and direct current systems, as well as for both synchronous and asynchronous motor operation.

In cases when a transformer is deemed necessary, it is an object of the present invention that the transformer shall be manufactured using a cable of the same type as and in a manner corresponding to the other electric machines included in the plant.

The advantage gained by satisfying the above objects is the avoidance of an intermediate, oil-filled transformer, the reactance of which otherwise consumes reactive power. Advantages are also gained in network quality since rotating compensation exists. With a plant according to the invention the overload capacity is increased up to, say +100%. The control area is larger than existing technology.

To achieve this, the magnetic circuit and its conductors in at least one of the electric machines included in the plant are produced with threaded permanently insulated cable and included earth.

The major and essential difference between known technology and the embodiment according to the invention is thus that the latter is achieved with a magnetic circuit included in at least one of the machines in the electric plant, which is arranged to be directly connected via breakers and isolators to a high supply voltage, up to between 20 and 800 kV, preferably higher than 36 kV. The magnetic circuit thus comprises one or more laminated cores with a winding consisting of a threaded cable having one or more permanently insulated conductors having a semiconducting layer both at the conductor and outside the insulation, the outer semiconducting layer being connected to earth potential.

To solve the problems arising with direct connection of electric machines, both rotating and static machines, to all types of high-voltage power networks, at least one machine in the plant according to the invention has a number of features as mentioned above, which differ distinctly from known technology. Additional features and further embodiments are defined in the dependent claims and are discussed in the following.

The features mentioned above and other characteristics of the plant and at least one of the electric machines included therein according to the invention, include the following:

- The winding for the magnetic circuit is produced from a cable having one or more permanently insulated conductors with two semiconducting layers, one surrounding the strands and one forming an outer sheath. Some typical conductors of this type have insulation of cross-linked polyethylene (PEX) or ethylene propylene rubber. For the present purpose the conductors may be further developed both as regards the

strands in the conductor and the nature of the outer sheath.

- Cables with circular cross section are preferred, but cables with some other cross section may be used in order to obtain better packing density, for instance.
- Such a cable allows the laminated core to be designed according to the invention in a new and optimal way as regards slots and teeth.
- The winding is preferably manufactured with insulation in steps for best utilization of the laminated core.
- The winding is preferably manufactured as a multi-layered, concentric cable winding, thus enabling the number of coil-end intersections to be reduced.
- The slot design may be suited to the cross section of the winding cable so that the slots are in the form of a number of cylindrical openings running axially and/or radially outside each other and having an open waist running between the layers of the armature winding.
- The design of the slots may be adjusted to the relevant cable cross section and to the stepped insulation of the winding. The stepped insulation allows the magnetic core to have substantially constant tooth width, irrespective of the radial extension.
- The above-mentioned further development as regards the strands entails the winding conductors consisting of a number of impacted strata/layers, i.e. insulated strands that from the point of view of an electric machine, are not necessarily correctly transposed, uninsulated and/or insulated from each other.
- The above-mentioned further development as regards the outer sheath entails that at suitable points along the length of the conductor, the outer sheath is cut off, each cut partial length being connected directly to earth or a similar selected potential.

The use of a cable of the type described above allows the entire length of the outer semiconducting layer of the winding, as well as other parts of the plant, to be kept at earth potential. An important advantage is that the electric field is close to zero within the coil-end region

outside the outer semiconducting layer. With earth potential on the outer layer the electric field need not be controlled. This means that no field concentrations will occur either in the core, in the coil-end regions or in the transition between them.

The mixture of insulated and/or uninsulated impacted strands, or transposed strands, results in low stray losses.

The cable for high voltage used in the magnetic circuit winding is built up of an inner core/conductor with a plurality of strands, at least one semiconducting layer, the innermost semiconducting layer being surrounded by an insulating layer, which is in turn surrounded by an outer semiconducting layer having an outer diameter in the order of 10-250 mm and a conductor area in the order of 40-3000 mm^2.

According to a particularly preferred embodiment of the invention, at least two of these layers, preferably all three, have the same coefficient of thermal expansion. The decisive benefit is thus gained that defects, cracks and the like are avoided during thermal movement in the winding.

Since the insulation system, suitably permanent, is designed so that from the thermal and electrical point of view it is dimensioned for a conductor voltage of over 36 kV, the system can be connected to high-voltage power networks without any intermediate step-down transformer, thereby achieving the advantages referred to above.

The above-mentioned and other advantageous embodiments of the invention are defined in the dependent claims.

Brief description of the drawings:

The invention will be described in more detail in the following detailed description of preferred but non-limiting

embodiments, with reference to the accompanying drawings, in which:-

Figure 1 shows a schematic end view of a sector of the stator in an electric machine in the plant according to the invention;

Figure 2 shows an end view, step-stripped, of a cable used in the winding of the stator according to Figure 1;

Figure 3 is a schematic circuit diagram of a supply system including transformers wound according to the invention;

Figure 4 is a schematic circuit diagram of a supply system having a rotating converter unit;

Figure 5 shows an alternative embodiment of the supply system shown in Figure 4;

Figure 6 shows another embodiment of a supply system having a rotating converter unit;

Figure 7 shows an alternative embodiment of the supply system shown in Figure 6;

Figure 8 shows yet another embodiment of a supply system having a rotating converter unit;

Figure 9 shows a conventional supply system comprising filtering and load balancing means;

Figure 10 shows an embodiment of the invention suitable for replacing the system of Figure 9;

Figure 11 is a circuit diagram showing the embodiment of Figure 10 in more detail;

Figure 12 shows an embodiment of the invention utilising current booster transformers; and

Figure 13 shows an embodiment including a static converter unit.

Description of preferred embodiments:

In the schematic end view of a sector of a stator 1 according to Figure 1, pertaining to an electric machine of rotating type included in the plant according to the invention, the rotor 2 of the machine is also shown. The stator 1 is composed of a conventionally laminated core.

Figure 1 shows a sector of the machine corresponding to one pole pitch. A number of teeth 4 extend radially in from a yoke part 3 of the core towards the rotor 2 and are separated by slots 5 in which the stator winding is arranged. Cables 6 forming this stator winding are high-voltage cables which may be of substantially the same type as those used for power distribution, e.g. PEX cables. One difference is that the outer, mechanically-protective sheath, and the metal screen normally surrounding such power distribution cables are eliminated so that the cable for the present application comprises only the conductor and at least one semiconducting layer on each side of an insulating layer. Thus, the semiconducting layer lies naked on the surface of the cable.

The cables 6 are illustrated schematically in Figure 1, only the conducting central part of each cable part or coil side being drawn in. As can be seen, each slot 5 has varying cross section with alternating wide parts 7 and narrow waist parts 8. The wide parts 7 are substantially circular and surround the cabling. The waist parts 8 therebetween serve to radially fix the position of each cable. The cross section of the slot 5 also narrows radially inwards. This is because the voltage on the cable parts is lower the closer to the radially inner part of the stator 1 they are situated. Slimmer cabling can therefore be used towards the inside, whereas coarser cabling is necessary further out. In the example illustrated cables of three different dimensions are used, arranged in three correspondingly dimensioned sections 51, 52, 53 of slots 5.

Figure 2 shows a step-wise stripped end view of a high-voltage cable for use in an electric machine included in the plant according to the present invention. The high-voltage cable 6 comprises one or more conductors 31, each of which comprises a number of strands 36 which together give a circular cross section of copper (Cu), for instance. These conductors 31 are arranged in the middle of the high-voltage cable 6 and are surrounded in the embodiment shown by a part

insulation 35. However, it is feasible for the part insulation 35 to be omitted on one of the conductors 31. In the present embodiment of the invention the conductors 31 are together surrounded by a first semiconducting layer 32. Around this first semiconducting layer 32 is an insulating layer 33, e.g. PEX insulation, which is in turn surrounded by a second semiconducting layer 34. Thus the high-voltage cable of this invention need not include any metallic screen or outer sheath of the type that normally surrounds such a cable for power distribution.

The above description of the magnetic circuit for a rotating electric machine built up with the cable 6 is also applicable to static electric machines such as transformers, reactor windings and the like. A transformer having a winding formed from a cable as exemplified in Figure 2 is referred to herein as "a transformer of the invention". The following important advantages are obtained both from the design and the manufacturing point of view:

- the windings of the transformer can be constructed without consideration to any electric field distribution and the problematical transposition of parts in known technology is thus unnecessary,
- the transformer core can be designed without taking into consideration any electric field distribution,
- no oil is required for electric insulation of cable and winding and instead the cable and winding can be surrounded by air or by a non-flammable or slowly burning liquid,
- the lack of oil greatly reduces the risk of fire and explosion in a transformer of the invention, and hence fire walls are unnecessary,
- no special foundation having means for dealing with leaking oil is required,
- it is much easier to construct the transformer with the capability to withstand earthquakes,
- the transformer can be made rigid much more easily, due to its ability to withstand short circuits,
- the transformer is less noisy, cleaner and requires less maintenance,

- no special bushing is required as is the case for oil-filled transformers, for electrical communication between the outer connections of the transformer and the coils/windings located therein, and
- the manufacturing and testing technology required for a transformer of the invention with a magnetic circuit as described above, is considerably simpler than that required for conventional transformers/reactors.

The use of electric machines provided with magnetic circuits of the type described above enables the electric supply of traction motors, to be greatly simplified and made more efficient.

Certain embodiments of the invention which are described below include a rotating converter having at least one winding formed from the conductor exemplified in Figure 2, and referred to herein as "a rotating converter of the invention". The rotating converter may comprise a motor and a generator joined by a common shaft or may comprise a single machine having both motor and generator functions, as described in German Patents 372390, 386561 and 406371. The motor and generator may each be synchronous or asynchronous and the function of the rotating converter is to change the voltage, the number of phases and/or the frequency of the supply. For public frequency railway systems, the rotating converter can be a phase converter as described in Lueger, "Lexicon der Technik", Deutscher Verlags-Anstalt Stuttgart, Band 2, p.395, which also constitutes a single machine. It comprises two-phase windings and three-phase windings in the stator and a squirrel cage rotor.

In each of Figures 3 to 7, a known prior art supply system is shown on the left hand side of the Figure for comparison with the embodiment of the invention shown on the right hand side.

Figure 3 shows a typical public frequency (50 or 60 Hz) system. A 3 phase high voltage distribution line 40

supplies transformer stations, e.g. 41, 42 at several positions along the railway. The transformer stations are each fed from two of the three phases of the distribution line. Different phase combinations are used to balance the load. (Thus station 41 uses A-B, station 42 uses B-C, an adjacent station (not shown) uses C-A and so on). Each transformer station consists of high voltage switchgear 43, e.g. two transformers 44,45 and high or medium voltage switchgear 46 (although a single transformer per station may suffice). Between each two transformer stations switchgear 47 makes it possible to connect the overhead catenary wire sections 48,49 to each other. In the configuration shown, with a double track the two overhead catenary wires supplied from the same station are normally connected together at this central point. In most cases, an overhead catenary wire connection cannot be made between two different transformer stations since they are connected to different phases on the public net and such a connection would therefore result in unstable conditions. A disadvantage with this system is that a locomotive can not be supplied from both ends of an overhead catenary wire. The transformer stations must therefore be close to each other, typically 30 km apart. The transformers 44 in prior art station 41 are oil insulated and they are a threat to the environment. The large amount of transformer oil is also dangerous in case of fire. They must be checked for leaks on a regular basis. If there is other equipment close to the transformer, there must be a volume under the transformer, protected so the oil can not catch fire, where the oil can flow, in case of a leak. The transformers 44 are often protected from damage by walls made of concrete placed around them. If the transformer is located close to other equipment or inside a building, firewalls are often built around the transformer to protect the other equipment in case of a transformer oil fire. Fire extinguishing equipment can also be installed around the transformer.

By contrast, transformers 45 are transformers of the invention which do not contain anything inside that can leak

out to the environment. Another advantage is that in case of a fire, the fire will be much less severe. The transformer 45 can be placed on a much simpler foundation, i.e. a concrete socket.

Figure 4 shows a typical low frequency system. A 3 phase high voltage distribution line 40 supplies frequency converter stations e.g. 51,52 at several positions along the railway. At each converter station the three phase public frequency high voltage is first transformed down to medium voltage. The three phase medium voltage is then converted to single phase low frequency medium voltage. The known frequency converter 53 can be of static (as shown) or rotating type. There is switchgear at the HV side of the transformer, between the transformer and the converter and on the low frequency side of the converter. The static converter is a converter transformer transforming the medium voltage to a lower six-phase voltage. On rare occasions this converter transformer may be fed directly from the high voltage switchgear.On the overhead catenary wire 54, between two converter stations there is switchgear making it possible to connect the overhead catenary wire sections to each other and to synchronize them. An advantage with this system compared with a public frequency system is that a locomotive can be supplied from both ends of a overhead catenary wire. The converter stations can therefore be located further apart, typically 50-100 km.

The rotating converter 54 shown to the right of Figure 4 is a rotating converter of the invention. The advantage with this system is that the rotating converter 54 can be connected directly to the high voltage switchgear 55, without any intermediate transformer or switchgear. There is also no need for any transformer on the MV side even if the voltage of the overhead catenary wire is higher than 25 kV.

It may, however, be necessary or economical to provide a transformer between the 3 phase distribution line 40 and

the rotating converter 54 and Figure 5 shows an alternative system including such a transformer 56, which may be a transformer of the invention.

Figure 6 shows a typical low frequency system in Sweden. A 3 phase high voltage distribution line 40 supplies frequency converter stations e.g. 60,61 at strategic positions along the railway. At the converter station the three phase public frequency high voltage is first transformed at transformer 62 down to medium voltage. The three phase medium voltage is then covered to single phase low frequency medium voltage by a known static frequency converter 63.

The low frequency single phase voltage is then connected to the overhead catenary wire 64 but also transformed at transformer 65 up to high voltage, i.e. 132 kV. This higher voltage is transmitted to transformer stations, at which the voltage is transformed down to medium voltage again and connected to the overhead catenary wire. There is switchgear at the HV side of the transformer 62, between the transformer 62 and the converter 63, on the low frequency side of the converter 63 and at the high voltage side of the single phase transformer 65. The transformer stations in between the converter stations have high voltage switchgear on the HV side of the transformer and a medium voltage switchgear on the other side of the transformer.

An advantage with this system compared with a public frequency system is that a locomotive can again be supplied from both ends of a overhead catenary wire. Another advantage is that the high voltage transmission to the transformer stations in between the converter stations makes it possible to reduce the number of converter stations. The use of the higher transmission voltage (132 kV in Sweden) results in a much more efficient transmission of power. The total amount of installed converter capacity can therefore be reduced. The converter stations can therefore be

located with a longer distance between each two, typically 300-400 km. The transformer stations are located about every 20-40 km for a 16.5 kV, 16⅔ kV system (in Sweden).

The right hand side of Figure 6 shows a rotating convertor 66 of the invention, between HV switchgear 67 and MV switchgear 68. The advantage with this system is that the rotating converter 66 can be connected directly to the high voltage switchgear 67, without any intermediate transformer.

Figure 7 shows a system varying from that of Figure 6 in that a rotating converter 69 of the invention comprises a generator having two outputs, supplying both the catenary wire 64 and the high voltage, low frequency line 70.

The right hand side of Figure 8 shows a typical low frequency system used in Germany, Austria and Switzerland and by Amtrak in the USA. A 3 phase high voltage distribution line 40 supplies frequency converter stations e.g. 80 at strategic positions along the railway. At the converter station 80 the three phase public frequency high voltage is first transformed down to medium voltage. The three phase medium voltage is then converted to single phase low frequency medium voltage. The frequency converter can be of static (as shown) or rotating type. The low frequency single phase voltage is then transformed up to high voltage, i.e. 138 kV. This higher voltage is transmitted to transformer stations e.g. 81 located about every 10 km for an 11 kV, 25 Hz system (in the USA) or every 20-40 km (in Sweden) along the railway in between the converter stations. At these transformer stations the voltage is transformed down to medium voltage again and connected to the overhead catenary wire 82. There is switchgear at the HV side of a transformer 83, between the transformer 83 and the converter 80, on the low frequency side of the converter 80 and at the high voltage side of a single phase transformer 84. The transformer station 81 in between converter stations has high voltage switchgear on the HV side of its transformer 85

and medium voltage switchgear on the other side of the transformer 85. This system has all the advantages of the systems shown in Figures 6 and 7.

According to an embodiment of the invention shown on the left hand side of Figure 8, a rotating converter 86 of the invention is connected between HV switchgear and MV switchgear. The advantage with this system is that the rotating converter 86 can be connected directly to the high voltage switchgear, without any intermediate transformer or switchgear and be connected directly to the high voltage low frequency switchgear without any intermediate transformer or switchgear. Transformer 85 can be a transformer of the invention.

Figure 9 shows a known principle for a public frequency system, requiring a filter system 90 and a load balancing system 91 to balance the load and to reduce the disturbance which reaches the supplying public net. Autotransformers 92 can be used to improve the voltage along the overhead catenary wire 93. Interference with other systems is reduced by the use of autotransformers. The overhead catenary wire is normally sectionalized, which reduces the transmission capability.

Figure 10 shows that a system with rotating converters 95 of the invention does not need the filters and load balancing equipment shown in Figure 9 and that the overhead catenary wire can be synchronized and can connect the supplying stations together. The output voltage and frequency of the rotating converter 95 can be chosen from a wide range. For a public frequency railway system, the rotating converter preferably comprises a phase converter as described in Lueger, "Lexicon der Technik".

Figure 11 comprises schematic circuit diagrams showing the autotransformer principle in more detail. Autotransformers are used both in public frequency systems and in low frequency systems. The spacing between

autotransformers is not very far, e.g. 5-20 km. The fact that these transformers contain oil, typically 5000 kg, that can leak out and burn is bad for the environment.

The autotransformer 100, connected to high or medium voltage switchgear 101, is an autotransformer of the invention and does not contain anything inside that can leak out to the environment. Any fire which may occur will be much less severe and the autotransformer 100 can be placed on a much simpler foundation, i.e. a concrete socket.

The current to the locomotive is transferred only through the overhead catenary wire. There are however several possible paths that the return current can take:

Through the track;
Through the earth from any position along the track;
Through earth wires connected to the track;
Leakage through metal in the earth such as cable shields, pipes, fences and so on;
Return current conductors in parallel with the overhead catenary wire.

In most situations return current conductors are to be preferred, particularly in populated areas where a large current through, for example, a gas pipe is dangerous. The current will then flow both through the return conductor and through the other possible current paths.

If an AC system is used, current transformers with ratio 1:1 can be used. The return current in the return conductor is then forced to be the same as the current in the overhead catenary wire. The transformers are often named current booster transformers. They can be used in systems with or without return current conductors.

A system with autotransformers is not only used to give protection against unwanted return currents. Such a system also has a higher transmission capability. The system has

a negative feeder with a voltage which is 180 degrees out of phase with the voltage on the overhead catenary wire. The transformer is connected between the two feeders and the centre of the winding is connected to the track.

Figure 12 shows an embodiment of the invention including current booster transformers 110 of the invention. Current booster transformers are used both in public frequency systems and in low frequency systems. The spacing between current booster transformers is not very far, for example 2-5 km. The fact that known current booster transformers contain oil, typically 560 kg, that can leak out and burn is bad for the environment. The current booster transformers 110 of the invention do not contain anything inside that can lead out to the environment. Another advantage is that in case of a fire, the fire will be much less severe.

Figure 13 is a single line diagram of a typical Static Converter Unit. There are two transformers of the invention in this unit, T1 and T2. The system of Figure 13 is adapted from a known system comprising oil insulated transformers. The transformers T1,T2 do not contain anything inside that can leak out to the environment. Any fire occurring will be much less severe and the transformers T1,T2 can be placed on a much simpler foundation, i.e. a concrete socket.

The invention is not limited to the systems described above with reference to the drawings, but encompasses similar systems falling within the appended claims.

Conveniently the insulating layer 33 comprises solid thermoplastics material, such as polyethylenes of low or high density, polypropylene, polybutylene, polymethylpentene, ethylene ethyl acrylate copolymer, cross-linked materials such as PEX, or rubber insulation, such as ethylene propylene rubber or silicone rubber. The semiconducting layers 32, 34 may comprise similar material to the insulating layer 33 but with conducting particles,

such as carbon black, soot or metallic particles, embedded therein.

Although it is preferred that the electrical insulation should be extruded in position, it is possible to build up an electrical insulation system from tightly wound, overlapping layers of film or sheet-like material. Both the semiconducting layers and the electrically insulating layer can be formed in this manner. An insulation system can be made of an all-synthetic film with inner and outer semiconducting layers or portions made of polymeric thin film of, for example, PP, PET, LDPE or HDPE with embedded conducting particles, such as carbon black or metallic particles and with an insulating layer or portion between the semiconducting layers or portions.

For the lapped concept a sufficiently thin film will have butt gaps smaller than the so-called Paschen minima, thus rendering liquid impregnation unnecessary. A dry, wound multilayer thin film insulation has also good thermal properties.

Another example of an electrical insulation system is similar to a conventional cellulose based cable, where a thin cellulose based or synthetic paper or non-woven material is lap wound around a conductor. In this case the semiconducting layers, on either side of an insulating layer, can be made of cellulose paper or non-woven material made from fibres of insulating material and with conducting particles embedded. The insulating layer can be made from the same base material or another material can be used.

Another example of an insulation system is obtained by combining film and fibrous insulating material, either as a laminate or as co-lapped. An example of this insulation system is the commercially available so-called paper polypropylene laminate, PPLP, but several other combinations of film and fibrous parts are possible. In these systems various impregnations such as mineral oil can be used.